water

MDPI

Editorial

Overview of Landslide Hydrology

Roy C. Sidle [1,2,*], Roberto Greco [3] and Thom Bogaard [4]

1 Mountain Societies Research Institute, University of Central Asia, Khorog GBAO 736000, Tajikistan
2 Sustainability Research Centre, University of the Sunshine Coast, 90 Sippy Downs Dr., Sippy Downs 4556, Queensland, Australia
3 Dipartimento di Ingegneria, Università degli Studi della Campania 'L. Vanvitelli', via Roma 9, 81031 Aversa (CE), Italy; Roberto.GRECO@unicampania.it
4 Department of Water Management, Delft University of Technology, PO Box 5048, 2600 GA Delft, The Netherlands; t.a.bogaard@tudelft.nl
* Correspondence: roy.sidle@ucentralasia.org; Tel.: +996-770-822-144

Received: 11 January 2019; Accepted: 15 January 2019; Published: 16 January 2019

Most landslides and debris flows worldwide occur during or following periods of rainfall, and many of these have been associated with major disasters causing extensive property damage and loss of life [1–9]. Given concerns about the effects of climate change on precipitation regime, in the future, some mountainous areas may likely experience more landslides with a faster response to rainfall; however, most such projections are weakly based and remain untested [10,11].

Subsurface hydrology is usually the main triggering mechanism of these landslides and associated debris flows. While the effects of hillslope hydrology on runoff generation have been thoroughly studied, much less attention has been paid to these effects on landslide and debris flow initiation. Recent syntheses demonstrate that it is no longer appropriate to view the subsurface as a static media which facilitates the transit of subsurface water, rather a variety of factors affecting the dynamics of subsurface hydrology need to be considered [12,13]. This dynamic nature of subsurface hydrology depends on the complex interactions among precipitation inputs, physical properties and heterogeneity of soils and bedrock, local geomorphology, and vegetation and associated biomass. These factors influence the timing of landslides with respect to precipitation inputs and antecedent soil moisture [14–17], the mass and mode of failure [18], and the extent of runout or transformation of landslides into debris flows [19].

Both the infiltration of rainwater and snowmelt and bedrock exfiltration provide the local trigger of these landslides, while drainage and evapotranspiration tend to stabilize hillslopes by rerouting and removing subsurface water. Subsurface hydrology is strongly affected by preferential flow within the soil, substrate topography, and exfiltration from fractures in bedrock [2,13,18,20–22]; the overall regolith moisture regime and recharge rates are influenced by evapotranspiration, soil development processes, soil water-groundwater interactions, and landform aspect and shape [14,16,23–25]. The dynamic behavior amongst these interacting hydro-eco-geomorphic components evolves across spatial and temporal domains creating the conditions for landslide initiation. As such, the resulting hydrologic dynamics that induce changes in soil moisture and pore water pressure remain an important focal area of investigation and are addressed in this special issue along with hydro-meteorological thresholds for landslide assessment and early warning and modelling [15,17].

Incorporation of complex hydrological processes into landslide simulations is still lacking and has significantly lagged the development of reliable predictive hydrodynamic models for landslide occurrence. This conundrum is largely due to the complexities of both the regolith properties and the different modes of failure. In addition to the complications of simulating subsurface flow, monitoring groundwater levels and soil moisture in unstable terrain is challenging due to the large areas involved and diverse topographies.

Furthermore, challenges remain associated with landslide runout, i.e., the spatial propagation of landslide sediments. In mountainous terrain, a threshold appears to exist between landslide dam formation in receiving channels and debris flow occurrence associated with topographic conditions, water content, and the lithology from which sediment is derived [19]. Hydraulic modeling studies have reasonably predicted the spatial propagation of pumice debris flows [26]. Findings from flume experiments were used to develop a hydro-mechanical model for debris flow initiation, including rainfall thresholds [27]. Other modeling investigations included in this special issue examined the role of exfiltration from bedrock fractures on slope failure [18] and the influence of variable bedrock topography coupled with rainfall intensity on slope stability [22].

The thirteen papers presented herein address numerous landslide hydrology issues in five different continents. These studies cover a variety of soils and lithologies in climates ranging from tropical to Mediterranean to temperate. Failure modes include the full range from progressive soil creep to shallow, rapid landslides and debris flows. As such, these papers provide a significant contribution to the developing literature on landslide hydrology.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Basu, S.R.; De, S.K. Causes and consequences of landslides in the Darjiling-Sikkim Himalayas, India. *Geogr. Polon.* **2003**, *76*, 37–52.
2. Sidle, R.C.; Chigira, M. The July 20, 2003, Landslides and debris flows in southern Kyushu, Japan. *Eos Trans. Am. Geophys. Union* **2004**, *85*, 145–151. [CrossRef]
3. Nadim, F.; Kjekstad, O.; Peduzzi, P.; Herold, C.; Jaedicke, C. Global landslide and avalanche hotspots. *Landslides* **2006**, *3*, 159–173. [CrossRef]
4. Keefer, D.K.; Larsen, M.C. Assessing landslide hazards. *Science* **2007**, *316*, 1136–1138. [CrossRef] [PubMed]
5. Harp, E.L.; Reid, M.E.; McKenna, J.P.; Michael, J.A. Mapping of hazard from rainfall-triggered landslide in developing countries: Examples from Honduras and Micronesia. *Eng. Geol.* **2009**, *104*, 295–311. [CrossRef]
6. Hilker, H.; Badoux, A.; Hegg, C. The Swiss flood and landslide damage database 1972–2007. *Nat. Hazards Earth Syst. Sci.* **2009**, *9*, 913–925. [CrossRef]
7. Sidle, R.C.; Al-Shaibani, A.M.; Kaka, S.L.I. Geomorphic hazards in south-west Saudi Arabia: The human-environmental nexus. *Area* **2018**. [CrossRef]
8. Saito, H.; Matsuyama, H. Catastrophic landslide disasters triggered by record-breaking rainfall in Japan: Their accurate detection with normalized soil water index in the Kii Peninsula for the year 2011. *SOLA* **2012**, *8*, 81–84. [CrossRef]
9. Segoni, S.; Rosi, A.; Fanti, R.; Gallucci, A.; Monni, A.; Casagli, N. A regional scale landslide warning system based on 20 years of operational experience. *Water* **2018**, *10*, 1297. [CrossRef]
10. Alvioli, M.; Melillo, M.; Guzzetti, F.; Rossi, M.; Palazzi, E.; von Hardenberg, J.; Brunetti, M.T.; Peruccacci, S. Implications of climate change on landslide hazard in Central Italy. *Sci. Total Environ.* **2018**, *630*, 1528–1543.
11. Yeh, H.-F.; Tsai, Y.-J. Effect of variations in long-term rainfall intensity on unsaturated slope stability. *Water* **2018**, *10*, 479. [CrossRef]
12. Ehret, U.; Gupta, H.V.; Sivapalan, M.; Weijs, S.V.; Schymanski, S.J.; Blöschl, G.; Gelfan, A.N.; Harman, C.; Kleidon, A.; Bogaard, T.A.; et al. Advancing catchment hydrology to deal with predictions under change. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 649–671. [CrossRef]
13. Sidle, R.C.; Bogaard, T.A. Dynamic earth system and ecological controls on rainfall-initiated landslides. *Earth-Sci. Rev.* **2016**, *159*, 275–291. [CrossRef]
14. Belle, P.; Aunay, B.; Lachassagne, P.; Ladouche, B.; Join, J.-L. Control of tropical landcover and soil properties on landslides' aquifer recharge, piezometry and dynamics. *Water* **2018**, *10*, 1491. [CrossRef]
15. De Vita, P.; Fusco, F.; Tufano, R.; Cusano, D. Seasonal and event-based hydrological and slope stability modeling of pyroclastic fall deposits covering slopes in Campania (southern Italy). *Water* **2018**, *10*, 1140. [CrossRef]

16. Greco, R.; Marino, P.; Santonastaso, G.F.; Damiano, E. Interaction between perched epikarst aquifer and unsaturated soil cover in the initiation of shallow landslides in pyroclastic soils. *Water* **2018**, *10*, 948. [CrossRef]
17. Mirus, B.B.; Morphew, M.D.; Smith, J.B. Developing hydro-meteorological thresholds for shallow landslide initiation and early warning. *Water* **2018**, *10*, 1274. [CrossRef]
18. Weng, C.-H.; Lin, M.-L.; Lo, C.-M.; Lin, H.-H. The influence of groundwater on the sliding and deposition behaviors of cataclinal slopes. *Water* **2018**, *10*, 1179. [CrossRef]
19. Kharismalatri, H.S.; Ishikawa, Y.; Gomi, T.; Sidle, R.C.; Shiraki, K. Evaluating factors controlling sediment connectivity of landslide materials: A flume experiment. *Water* **2019**, *11*, 17. [CrossRef]
20. Montgomery, D.R.; Dietrich, W.E.; Heffner, J.T. Piezometric response in shallow bedrock at CB1: Implications for runoff generation and landsliding. *Water Resour. Res.* **2002**, *38*, 1274. [CrossRef]
21. Bogaard, T.A.; Greco, R. Landslide hydrology: From hydrology to pore pressure. *WIREs Water* **2016**, *3*, 439–459. [CrossRef]
22. Moradi, S.; Huisman, J.A.; Class, H.; Vereecken, H. The effect of bedrock topography on timing and location of landslide initiation using the local factor of safety concept. *Water* **2018**, *10*, 1290. [CrossRef]
23. Bogaard, T.A.; van Asch, T.W.J. The role of the soil moisture balance in the unsaturated zone on movement and stability of the Beline landslide, France. *Earth Surf. Process. Landf.* **2002**, *27*, 1177–1188. [CrossRef]
24. Loaiza-Usuga, J.C.; Monsalve, G.; Pertuz-Paz, A.; Arce-Monsalve, L.; Sanin, M.; Ramirez-Hoyas, L.F.; Sidle, R.C. Unraveling the dynamics of a creeping slope in northwestern Colombia: Hydrological variables, and geotechnical and seismic signatures. *Water* **2018**, *10*, 1498. [CrossRef]
25. Oorthuis, R.; Hürlimann, M.; Fraccica, A.; Lloret, A.; Moya, J.; Puig-Polo, C.; Vaunat, J. Monitoring of a full-scale embankment experiment regarding soil-vegetation-atmosphere interactions. *Water* **2018**, *10*, 688. [CrossRef]
26. Papa, M.N.; Sarno, L.; Vitiello, F.S.; Medina, V. Application of the 2D depth-averaged model, FLATModel, to pumiceous debris flows in the Amalfi Coast. *Water* **2018**, *10*, 1159. [CrossRef]
27. Van Asch, T.W.J.; Yu, B.; Hu, W. The development of a 1-D integrated hydro-mechanical model based on flume tests to unravel different hydrological triggering processes of debris flows. *Water* **2018**, *10*, 950. [CrossRef]